

Effect of EFB content on reducibility of low grade iron ore composite at 1000°C – 1200°C

H Purwanto¹, H M Salleh², A S Mohamad¹, A Zakiyuddin¹, A N Rozhan¹

¹Department of Manufacturing and Materials Engineering, International Islamic University Malaysia (IIUM), Jalan Gombak, 53100 Kuala Lumpur, Malaysia

²Department of Biotechnology Engineering, International Islamic University Malaysia (IIUM), Jalan Gombak, 53100 Kuala Lumpur, Malaysia

Email:hadi@iium.edu.my

Abstract. This paper focus on reduction of low grade iron at high temperature using palm oil empty fruit bunch as a reductant. The samples were crushed and compacted into composite pellet with EFB before drying at 110°C for 24 hours. The reduction test was then conducted by heating the composite pellet in an electric tube furnace. The parameter used was at temperature range 1000°C to 1200°C and under argon gas atmosphere. The efficiency of the empty fruit bunch in the reduction process was investigated based on the extent of reduction of the iron oxide. The results showed that the extent of reduction obtained was 38.97% at 1200°C. This study demonstrates that within the temperature range studied, reducibility of low grade iron ore with an empty fruit bunch tends to increase as the temperature increase.

1. Introduction

Malaysia has been developing on steel making since this industry is one of the strategic industries to promote the country to become a developed country in near future. Steel consumption has significantly increased year by year as reported by Malaysia Steel Industry Federation. Previously, iron ore is imported from other countries as Malaysia has no significant output of good quality iron ore for steel processing. At the same time, in 2014 almost 10 million tonnes are deposited from various mining area in Malaysia. This situation has led to an abundance of low iron ore and ways to utilize it efficiently and effectively is needed [1].

The present process of iron making in Malaysia using coal as the reducing agent in the reduction process of iron ore. However, some problems arising from the previous process of iron making, such as high demand of coal, higher energy consumption, environmental problems [2]. International Energy Statistics estimated about 59 million metric tonnes of CO₂ are given off from the total coal used in Malaysia until 2013.

At the same time, due to the depletion of high-grade resources, properties of natural resources such as iron ore and coal will change drastically [2]. Hence, alternative ways of utilizing low grade iron ore by replacing coal with biomass for iron making process has been taken. Many countries have been used biomass in iron and steel making, for instance in Brazil, biomass have been used as fuels and also as a reductant [3]. The idea of using biomass to replace coal is a promising alternative as biomass is a carbon-neutral and renewable fuel source and contain low amounts of harmful elements such as



sulphur and phosphorus [4]. Biomass are categorized as one of the most abundant element in the world, making it a feasible choice in replacing coke in iron and steel making as reductant.

The reduction process with several types biomass for iron making have been done by a previous researcher such as sawdust [2], [5], [6], rice husk [7], wood powder [8], chipped cedar [9], biomass char [3] -[10] and limited research have been done by using palm oil biomass. Hence this present research focused on potential of palm oil empty fruit bunch for the reduction process in reducing low grade iron ore into quality iron materials.

2. Experimental procedures

Raw material, of iron ore and oil palm empty fruit bunch (EFB) was taken from Bahau, Negeri Sembilan mining site and from palm oil mill at Mempaga, Bentong, Pahang. The raw materials were compacted to produce pellet with 10 mm – 20 mm in diameter [11]. Before undergoing reduction test the pellet was dried at 110°C for 24 hours to release moisture and chemical analysis of low grade iron ore used as raw material is provided in table 1.

Table 1. Chemical analysis of iron ore from Bahau, Negeri Sembilan.

Element	Fe _{total}	Al ₂ O ₃	MgO	SiO ₂	K ₂ O	TiO ₂	Cr ₂ O ₃	MnO
Content (%)	51.92	9.20	0.44	14.87	0.06	0.52	0.06	0.23

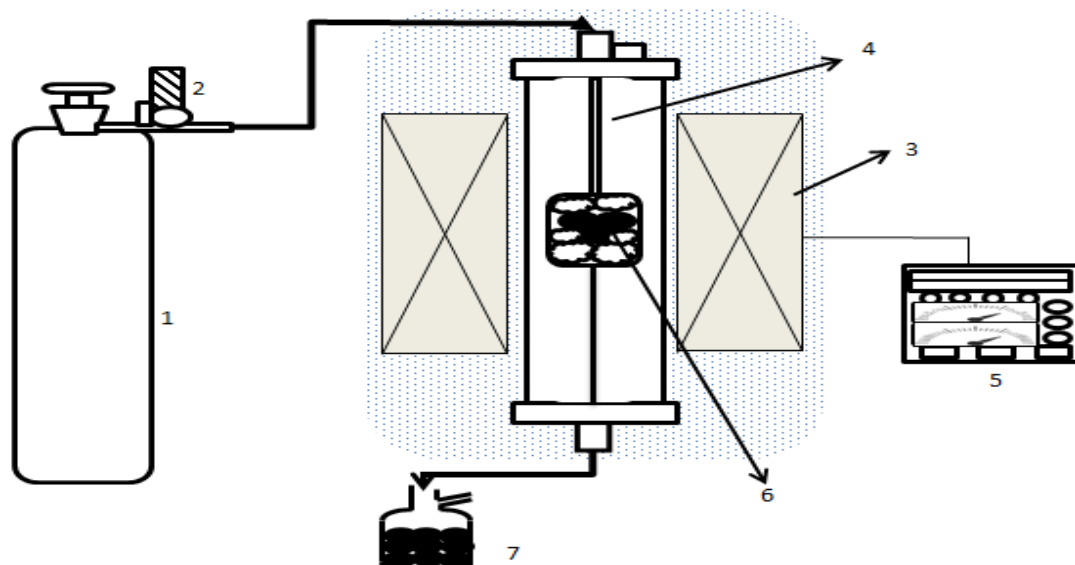


Figure 1. Schematic diagram of experimental apparatus (1- argon gas container, 2- gas controller, 3- electric heater, 4- thermocouple, 5- temperature controller, 6- composite pellet, 7- exhaust gas trap).

Reduction reaction of the pellet was conducted in a vertical electric tube furnace with a quartz tube reactor at the centre as schematically shown in figure 1. Inert condition was established by flowing argon gas into the furnace. For the reduction to be completed, the pellet was held for 30 minutes after heating at the desired temperature between 1000°C to 1200°C. Argon gas was kept flowing into the furnace until the end to ensure no oxidation occurred. The reduced composite pellet was then subjected to characterization to assess the extent of the reduction, magnetization properties, phase change and morphology as well as total iron content.

The complete reduction reaction occurred when hematite phase in the ore completely transformed into metallic iron phase. Transformation takes place when oxygen being removed from the ore and the amount of oxygen removed can be calculated referring to the molecular weights. For every phase transformation involved in reduction reaction the oxygen removed is estimated as shown in table 2. Calculation of extent of reduction and reducibility shown in equation (1) and (2) respectively.

Table 2. Estimation of oxygen removal

Reaction	Reductant	Oxygen removal (%)
$\text{FeO}(\text{OH}) \rightarrow \text{Fe}_2\text{O}_3$	CO / H ₂	2.5
$\text{Fe}_2\text{O}_3 \rightarrow \text{Fe}_3\text{O}_4$		3.33
$\text{Fe}_3\text{O}_4 \rightarrow \text{FeO}$		6.89
$\text{FeO} \rightarrow \text{Fe}$		22.22

$$\text{Extent of reduction} = W_{\text{pellet}} - W_{\text{ore}} - W_{\text{EFB}} \quad (1)$$

Where; W_{pellet} : weight loss of the composite pellet after the reduction process
 W_{biomass} : weight loss of the biomass during the thermal analysis
 W_{ore} : weight loss of the iron ore during the thermal analysis

$$\text{Reducibility} = \frac{\text{Extent of reduction}}{\text{Theoretical oxygen removal}} \quad (2)$$

3. Results and Discussion

The effect of reduction test at different temperature and composition can be observed in figure 2. As the temperature increases the size of the composite pellet decreases during reduction reaction at implying that the volume of the composite pellet decreases. At all temperatures tested iron with metallic gloss was detected in the composite pellets suggesting that EFB was able to reduce iron oxide into metallic iron.

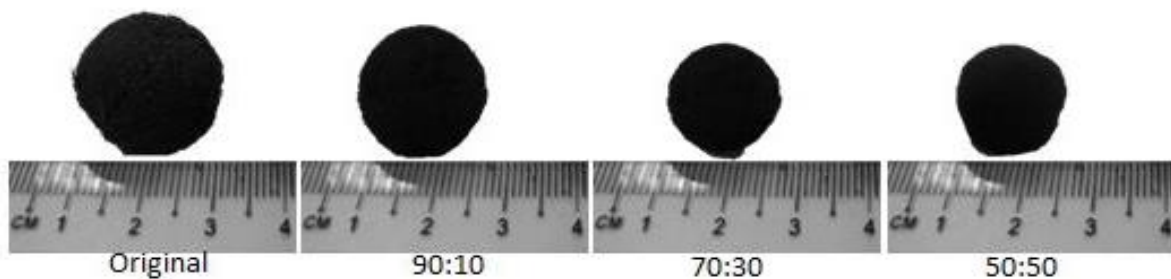


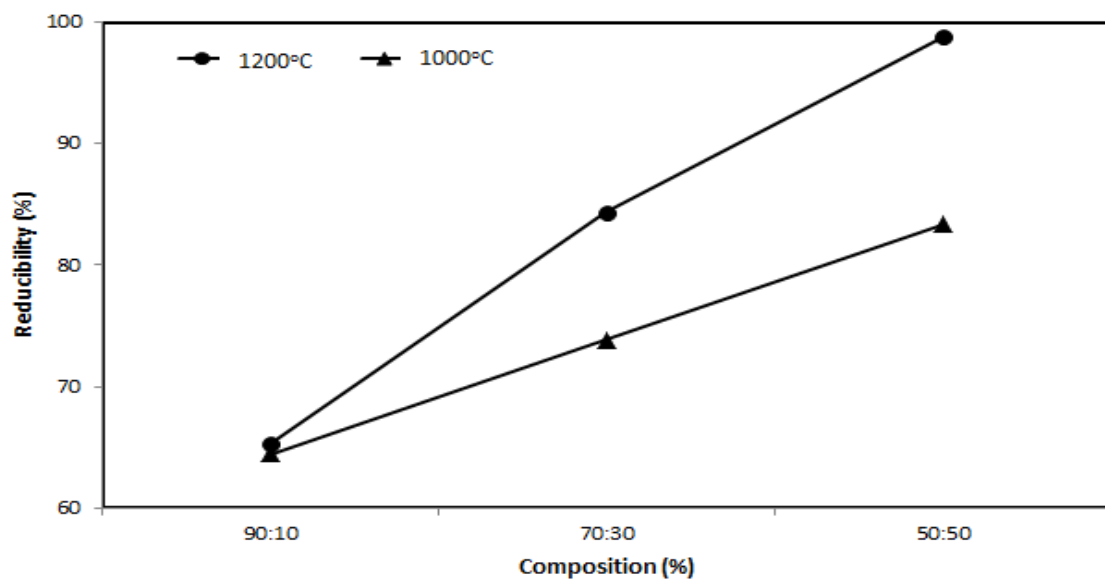
Figure 2. Physical changes of composite pellets of different composition before and after reduction at 1000° C.

Effect of composition on the extent of reduction of composite pellet at different temperatures shown in table 3. From the table it can be seen that extent of reduction reached the highest value of 38.97% at 1200°C. It can be observed that the extent of reduction was increased approximately 15% - 25% as the reaction proceeds from 1000°C to 1200°C. The extent of reduction corresponds to the increasing temperature as there was a reaction between the ore particles and the EFB as the reduction proceed. Based on the oxygen removed from iron ore the extent of reduction was calculated as shown in equation (3.1). Removal of oxygen from the iron oxide caused a phase change as the carbon in the EFB acted as a solid reductant during the reduction reaction.

Table 3. Extent of reduction with different composition at different temperature

Temperature (°C)	Composition (Iron ore: Biomass)	Extent of Reduction (%)
1000°C	90:10	25.42
	70:30	29.12
	50:50	32.87
1200°C	90:10	25.76
	70:30	33.27
	50:50	38.97

Figure 3 shows that the reducibility of the composite pellet is influenced by the reduction temperature and composition of the iron ore: EFB ratio. The reducibility of the reduced composite pellet was calculated using equation (3.2). Increasing the composition of EFB in the composite pellet and reduction temperature increases the reducibility, reflecting improvement in a reduction reaction. Generally, for every 1 tonne of iron ore processed 825 kg of CO₂ will be released when coke is used [12]. It is that indicated that 30 wt.% of EFB will give 84.36% reducibility and up to 98.80% was achieved when 50wt. % of EFB was used. This reduction proceeds very fast could be caused by the iron reduced by two different reductant which is hydrogen and carbon monoxide gas. Hence, the lab scale data suggest that by replacing 30wt.% of coke with EFB, the theoretical amount of can be reduced to 701.25 kg and up to 775.5 kg of CO₂ can be reduced when 50wt.% of EFB is used.

**Figure 3.** Effect of composition on the reducibility of composite pellets at different temperatures

4. Conclusion

The following conclusions were achieved when reduction test of iron ore with EFB at 1000°C and 1200°C was completed. Both parameters used in this research, temperature and composition were affected the reduction process of the composite pellet. Higher temperature and composition of EFB gives better extent of the reduction. Highest reducibility of 94.22% was achieved strongly at 1200°C compared to other temperature suggests that higher removal of oxygen is occurring at high temperature. Higher extent of reduction proved that the composite pellet was successfully reduced to another phase and metallic iron phase was dominant at 1200°C. In terms of feasibility study of the reduction reaction process using EFB, it was estimated that the theoretical maximum value of 775.5 kg of CO₂ can be reduced for each metric tonne of Bahau ore used.

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